

Relation Between Physical and
Magnetic Hardness of
Certain Carbon Steels

C. R. Snowdon
O. A. St. Clair

1905

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Relation between Physical and Magnetic
Hardness of Certain Carbon Steels.

A Thesis

by
E. R. Snodden
O. W. Clark
To the

President and Faculty
of

Armour Institute of Technology

For the Degree of

Bachelor of Science in Electrical Engineering
having completed the prescribed course of study
in Electrical Engineering.

June 9, 1905.

C. E. Freeman

Per Snodden

H. M. Raymond

Dean of Engineering

L. C. Morin

Dean of Cultural Studies

Relation between Physical and Magnetic Hardness of Certain Carbon Steels.

In choosing a subject for a thesis on the Magnetic Properties of Iron or Steel we were led to this particular line of investigation by the suggestion of Mr. John A. Mathews, Assistant Manager of the Crucible Steel Company of America, Syracuse, New York, made in a letter to Professor C. E. Freeman of Armour Institute of Technology. The specimens tested and their chemical analyses were procured from Mr. Mathews, who should be given credit for the idea, he having already made some tests with the view of ascertaining whether such a relation exists.

The chemical analyses of the steels are as follows:-

	(1)	(2)	(3)	(4)	(5)	(6)
Carbon	.36	.60	.89	1.16	1.26	1.37
Manganese	Trace	.14	.155	.17	.17	.16
Silicon	.14	.15	.19	.20	.16	.19
Phosphorus	.010	.	.010			.011
Sulphur	.011	.	.013			.012

Mr. Mathews says that "since the same raw materials were used in making these steels we may consider that the other Phosphorus and Sulphur values will be of the same order as those given." Specimen #1 is not a commercial steel but is from an experimental ingot, which accounts for the small percentage of Manganese.

Before beginning the physical and magnetic hardness tests the specimens were subjected to different annealing processes.

The samples for magnetic tests were cut to a length of ten inches and then machined to within about .015 inches of the diameter required by Esterline's Permeameter, which requires the diameter to be .575 inches. The specimens for physical hardness tests were cut to a length of approximately three-quarters of an inch.

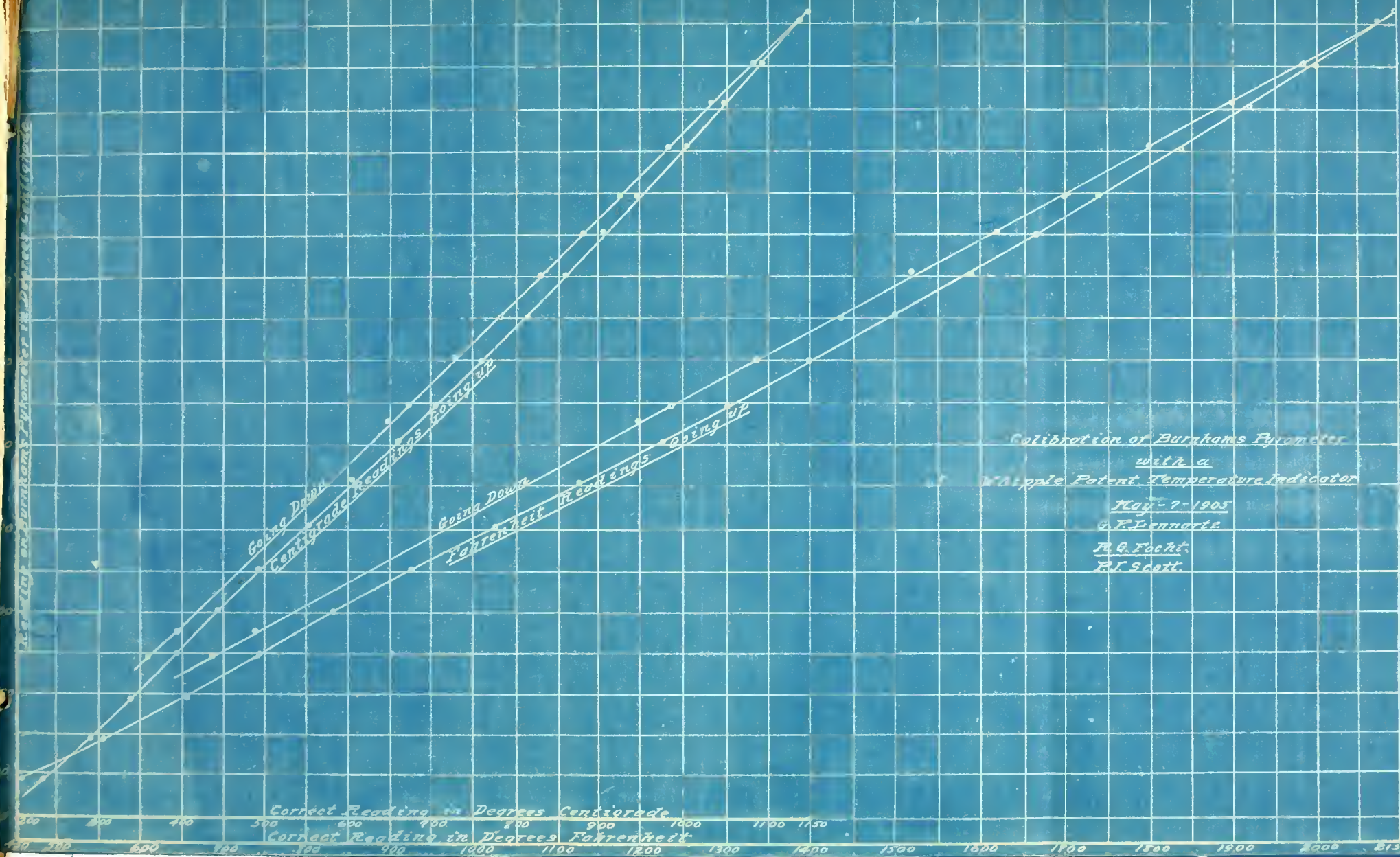
The two classes of specimens were numbered to correspond and were then placed in a cast iron box containing Magnesium Carbonate, which does not attack steel, then the whole placed in an annealing furnace. The furnace and the blower are shown in the following blue-print. The temperatures were indicated by means of Burnham's Pyrometer, which consists of a platinum-iridium couple connected to a calibrated millivoltmeter.

Set A of the specimens were tested in the condition in which they were received from the manufacturers.

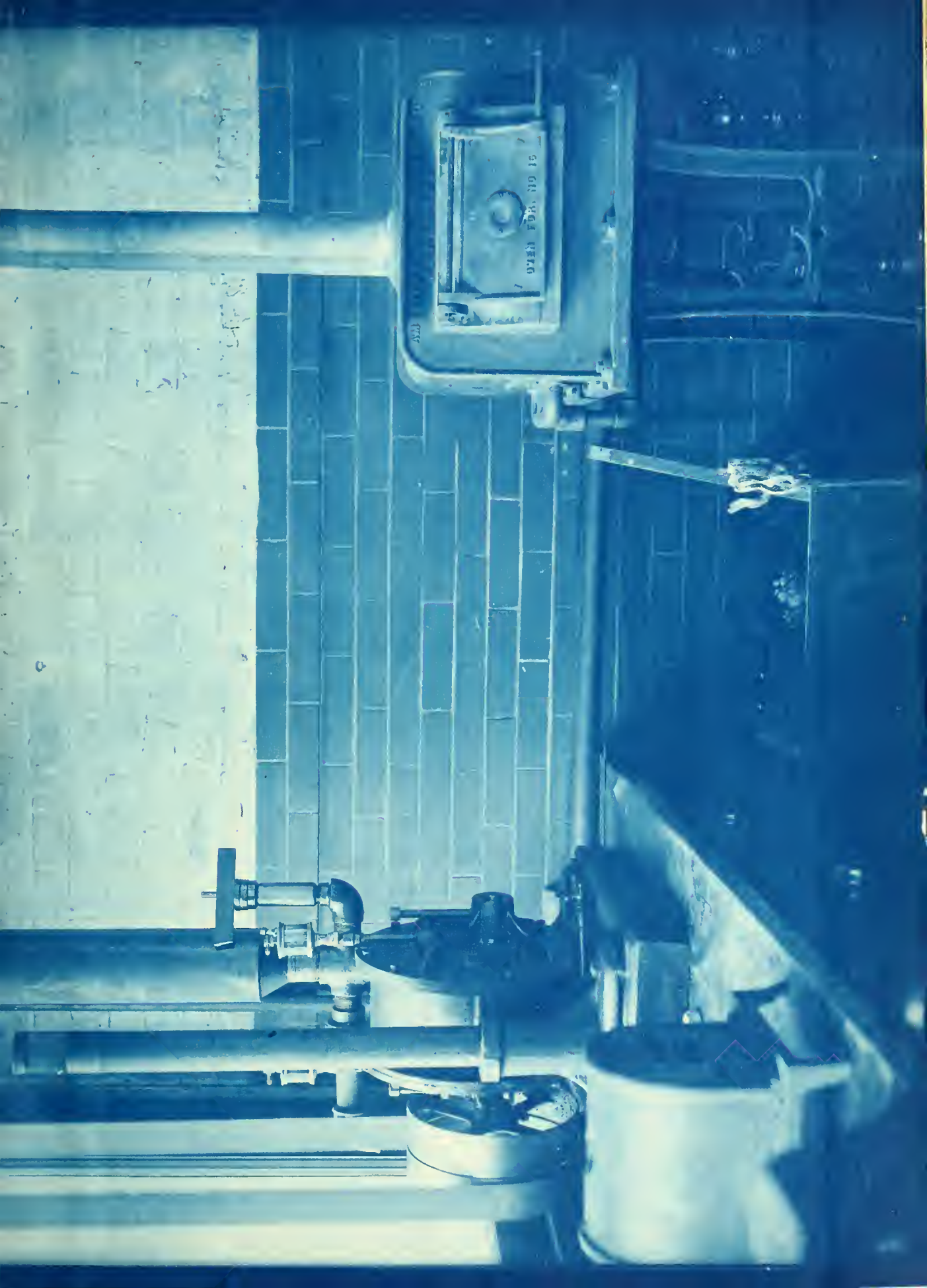
Set B was subjected to a "normalizing" heat of about 950 degrees C. for about three hours, i. e., a temperature which will remove any hardness due to the last rolling. The bars were allowed to cool in the air.

Set C was subjected to a heat of about 835 degrees C. which was not kept constant for any particular length of time but the temperature was slowly decreased until below the "hardening" temperature (about 675 degrees C.). The

Reading on Burkhoms Pyrometer in Degrees Centigrade



Calibration of Burkhoms Pyrometer
with a
Whipple Potent Temperature Indicator
May - 7 - 1905
A. F. Pennoke
R. G. Fackel
B. J. Scott.



fire was then turned out and the specimens allowed to cool in the furnace.

In Set D the temperature was raised to about 650 degrees C., i. e., a temperature which is below the hardening heat, and kept at this for two or three hours. The gas was then shut off and the specimens allowed to cool in the furnace.

Set E was raised to about 750 degrees C. and kept constant at this value for two or three hours and then dropped into a pail of water. This, however, made the specimens so hard that we were able to machine only one of them.

The Numbered specimens were subjected to a heat of about 900 degrees C. and kept at this value for three hours when the temperature was gradually lowered.

(Note:- By "hardening" temperature is meant that temperature above which the molecular structure changes.)

The relation between the time and temperature is shown by curves on the following pages, the curves being started at that temperature which we were first able to read on the pyrometer, 200 degrees C. by instrument. The correct temperatures were obtained from the calibration curve of the pyrometer, shown in blue-print.

The physical hardness specimens were ground to approximately three-quarters of an inch in length, both ends being ground.

On separate blue-prints are shown the scheme of making the hardness tests and the Riehle' machine used in making the tests.

A hardened steel ball was placed in a depression in a



Specimens B

Heat began at 9:40

Time	Pyrometer readings	Pyrometer readings
	temp. C	temp. C, corrected.
10:10	200	150
10:40	545	495
11:10	815	760
11:40	985	950
12:10	985	950
12:40	985	950
1:10	975	960
1:40	990	955
2:10	985	950
2:40	985	950

Removed and allowed to cool in air.

Specimen C.

Slow cooling until below hardening point.

Heat began at 9:35

Time	Pyrometer readings	Pyrometer readings
	temp. C.	temp. C, Corrected.
11:05	245	190
11:35	320	260
12:05	390	340
12:35	460	400
1:05	500	440
1:35	710	665
2:05	780	745
2 :35	870	835

2:50	855	780
3:05	828	755
3:20	815	740
3:35	790	725
3:50	755	680
4:05	725	650
4:15	712	635
4:20	700	625
4:25	690	620
4:30	680	605
4:35	660	585
4:40	645	570
4:45	628	550
4:50	615	540

Numbered Specimens.

Heat began at 8:35

9:05	260	195
9:20	400	345
9:35	595	540
9:50	640	600
10:05	795	725
10:20	870	835
10:35	950	910
11:05	950	910
11:35	960	915
12:05	940	875
12:35	960	915
1:05	960	915

1:35	960	915
2:00	850	780
2:30	765	700
3:00	720	650
3:30	680	610
3:45	625	550
4:20	512	440
4:35	470	385
4:45	445	360

Specimen D

Heat began at 8:35

Kept at constant temperature for two or three hours and cooled in furnace.

8:55	200	150
9:10	330	275
9:20	500	442
9:40	700	656
10:00	700	656
10:30	700	656
11:00	700	656
11:30	700	656
12:00	690	645
12:30	705	660
12:40	680	605
12:50	655	580
1:00	630	555
1:55	480	390

Specimens E.

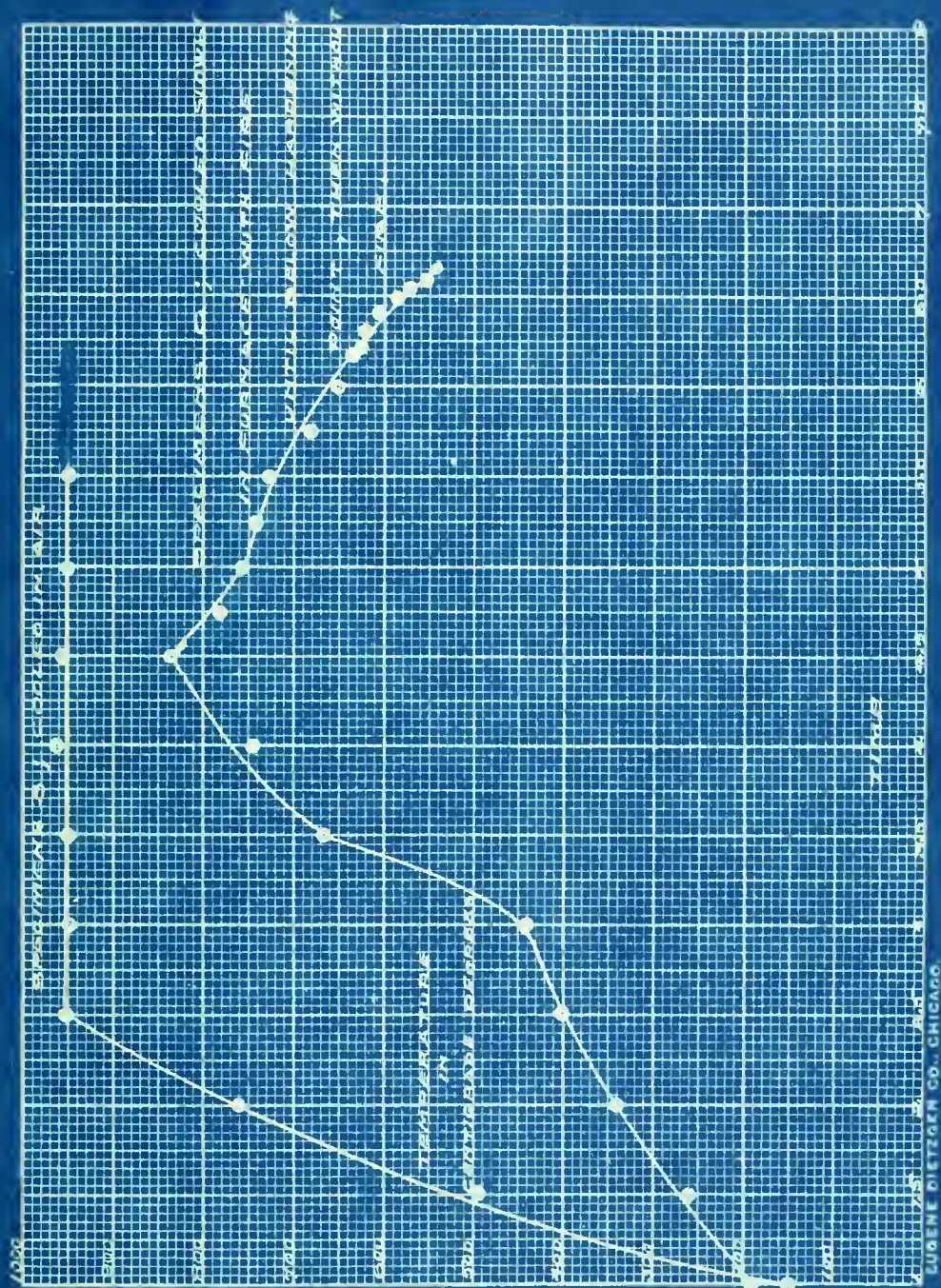
7. .

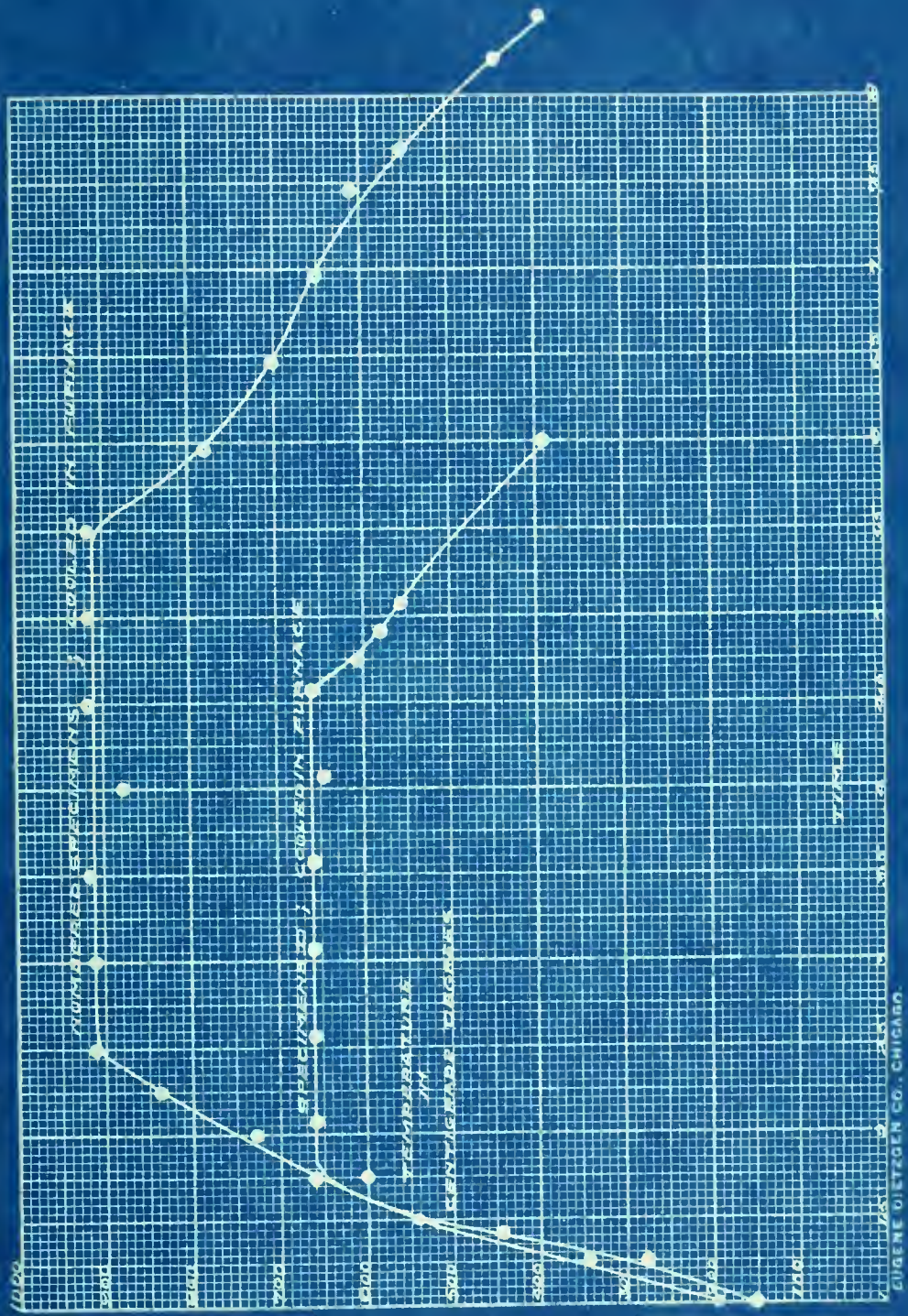
Kept at a constant heat for two or three hours and then cooled in water.

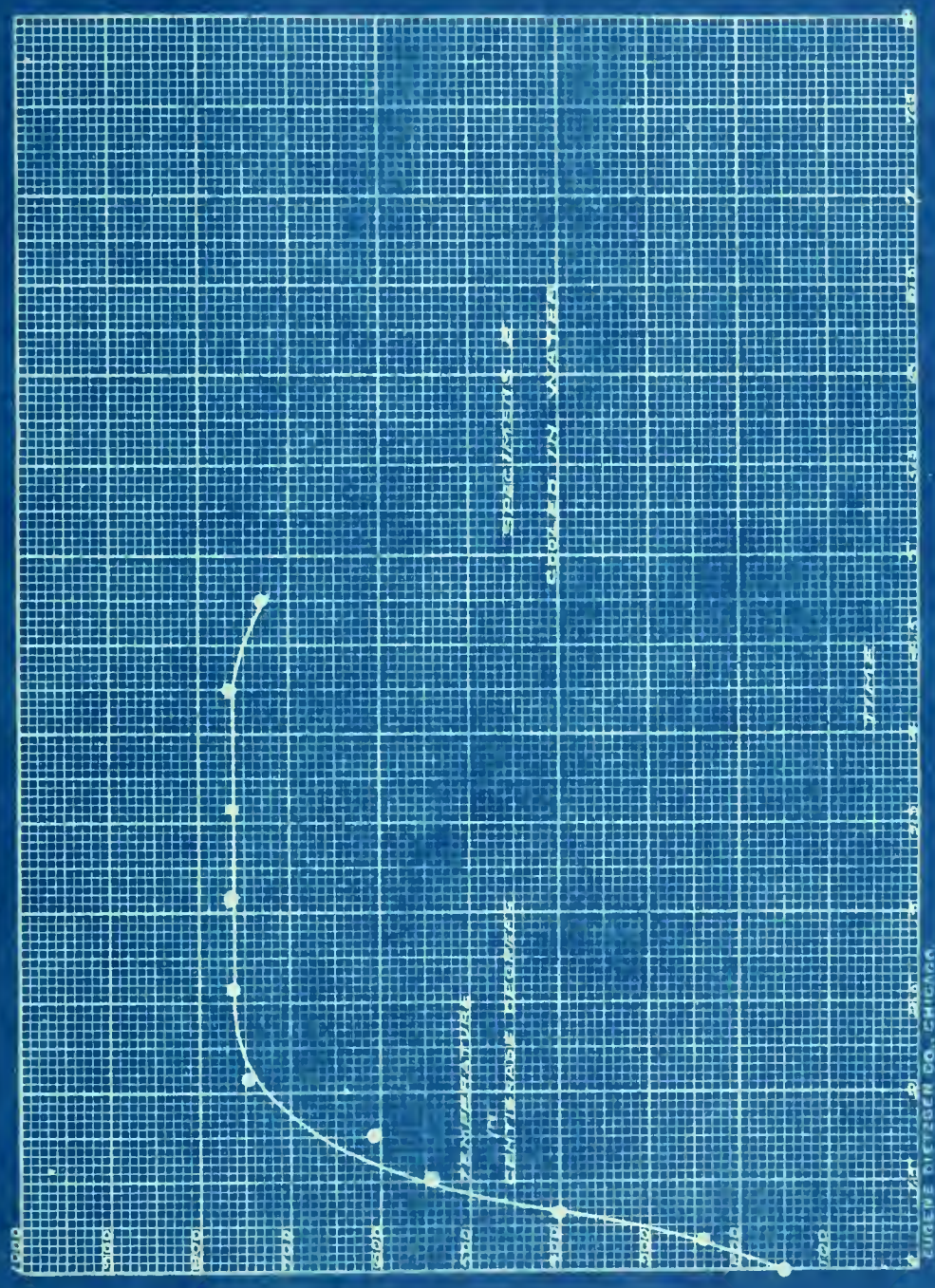
Heat began at 8:55.

9:15	200	150
9:25	300	240
9:35	460	400
9:45	600	545
10:00	680	605
10:20	780	745
10:50	800	762
11:20	800	762
11:50	800	762
12:30	815	765
1:00	800	730

(Note:- In the drawing of the curves for the preceeding data we started with the first reading of the temperature on the pyrometer and not with the original temperature of the Specimens).







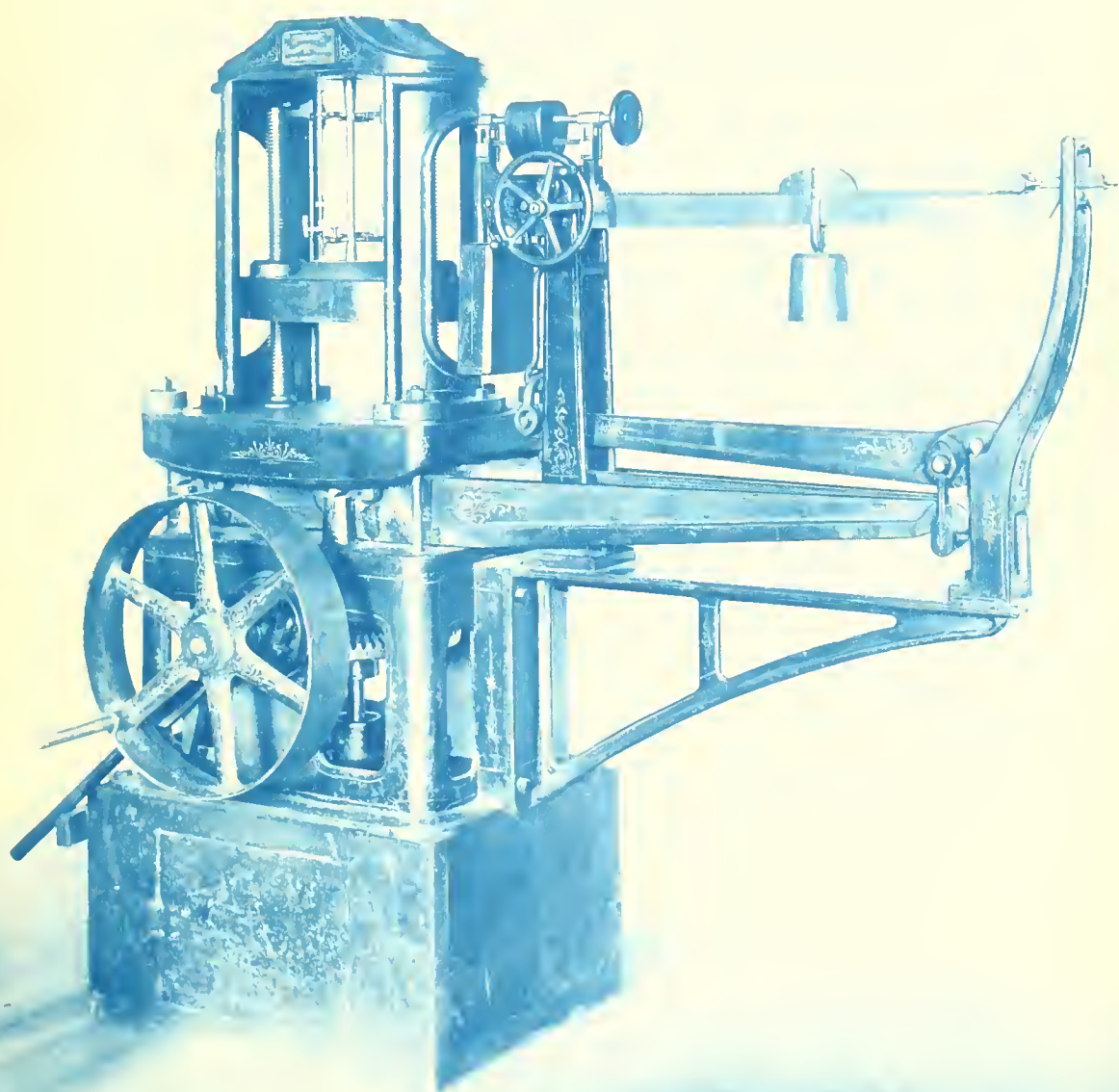
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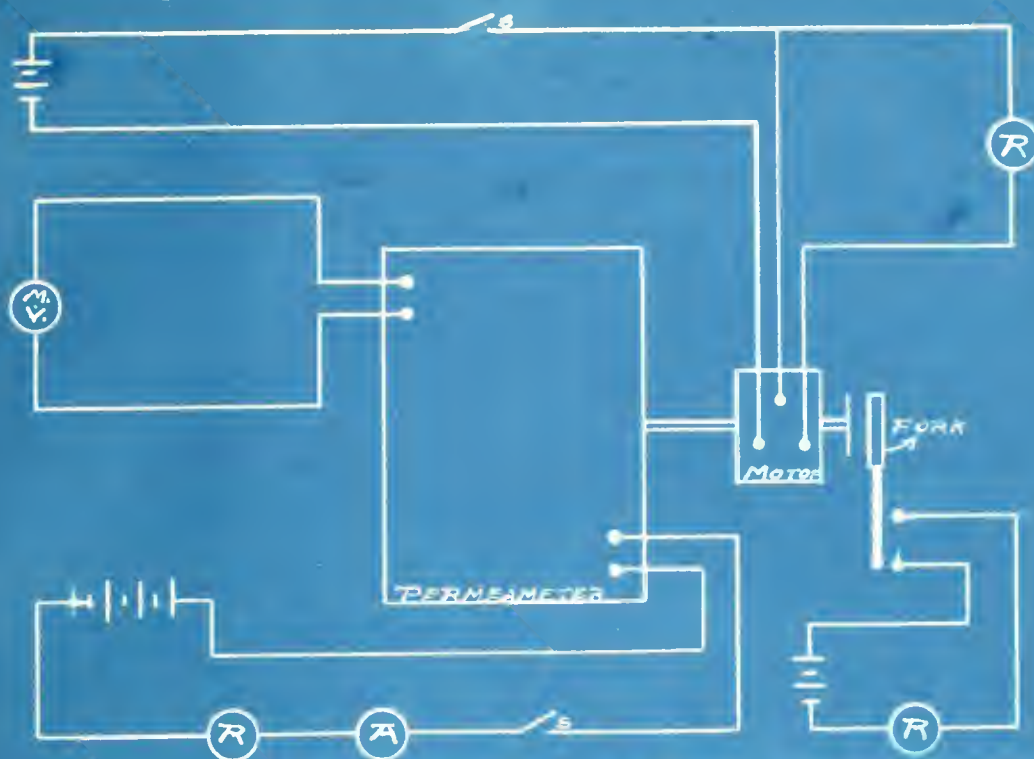
piece of hard steel, the specimen to be tested being placed in a cast iron block made to fit the Riehle machine, a small hole equal to the diameter of the specimen was made in the latter block. A force of 6000# was applied to force the ball into the specimen, approximately one minute being taken to apply the total load. After making a test on each end of the specimens we measured the diameters of the impressions by means of a stationary microscope and the movable table of a dividing-engine. The specimens to be measured were placed on the table and the distance through which it was moved was measured by means of the engine micrometer. This distance is the diameter of the impression. The average diameter of the two impressions of each test piece was taken as the true diameter.

From a table in the Journal of the Iron & Steel Institute, Volume I, 1901, we obtain the areas of impressions of certain diameters for a centimeter ball. Our ball was three-eighths inches (a little over size) in diameter so that the areas were a trifle small. However, the difference in area is not very great so we used the table in our calculations.

The apparatus used and the scheme of connecting this apparatus is shown by means of blue-prints.

The Esterline Permeameter is intended to be run by means of an induction motor but instead we used a Holtzer-Cabot one-tenth H. P. Direct Current shunt motor. The speed was kept constant at 1708 R. P. M., this speed being





~ SCHEME OF CONNECTIONS FOR MAGNETIC TESTS ~



~ SCHEME FOR PHYSICAL TESTS ~

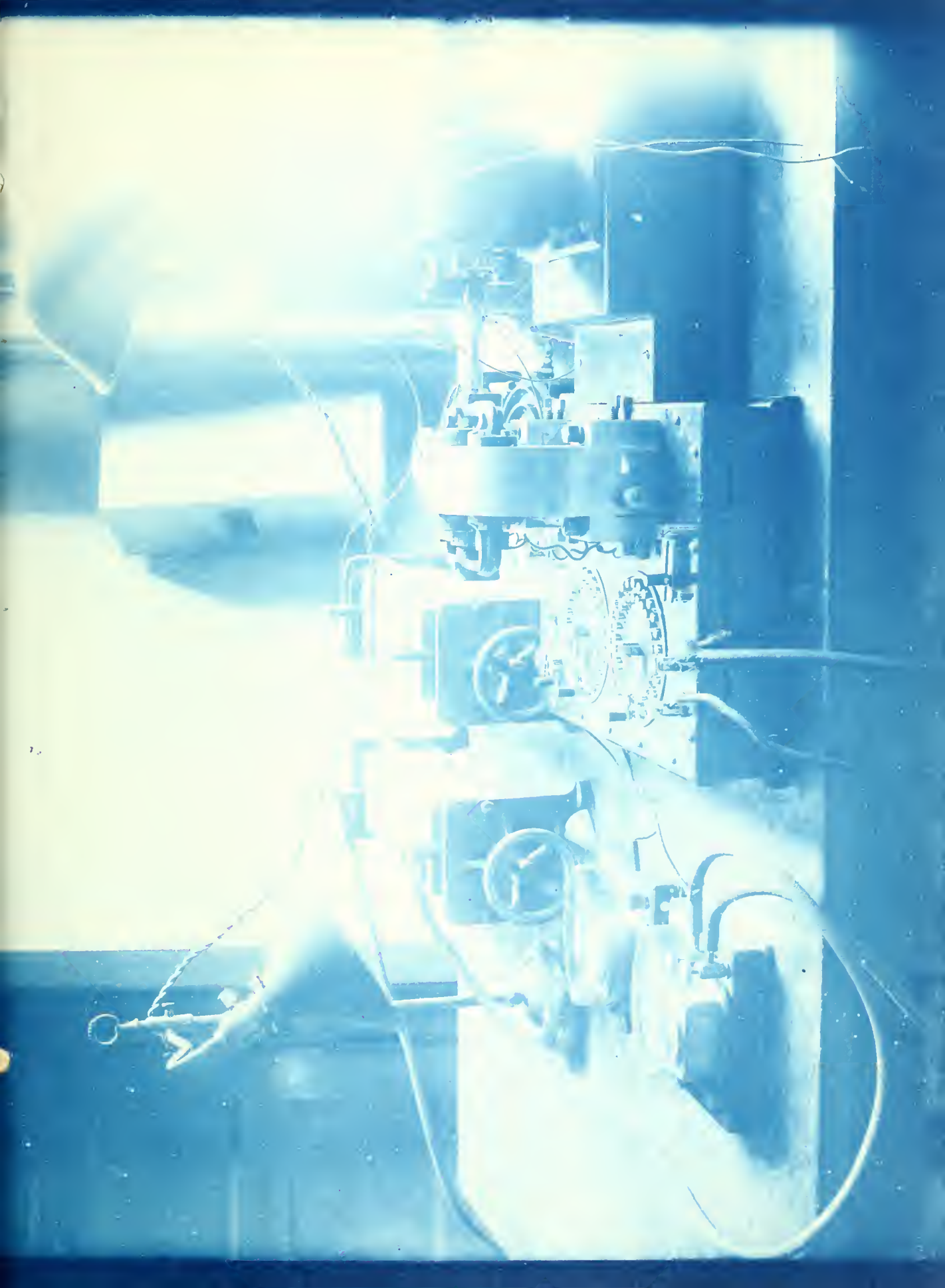


Table for Finding Area of Impression When Diameter of Impression is Known. Taken from Journal of Iron & Steel Institute, Vol. I, 1901.

D=Diameter of impression in millimeters.

A=Area of impression in square millimeters.

D & A are given for a ball 10 mm. in diameter.

D	A	D	A	D	A
1.50	1.8095	2.55	5.1931	3.60	10.5338
1.55	1.8975	2.60	5.4036	3.65	10.8416
1.60	2.0232	2.65	5.6188	3.70	11.1495
1.65	2.1866	2.70	5.8340	3.75	11.4495
1.70	2.2871	2.75	6.0586	3.80	11.7496
1.75	2.4378	2.80	6.2832	3.85	12.0951
1.80	2.5761	2.85	6.5172	3.90	12.4407
1.85	2.7112	2.90	6.7513	3.95	12.7785
1.90	2.8620	2.95	6.9696	4.00	13.1162
1.95	3.0159	3.00	7.1880	4.05	13.4712
2.00	3.1762	3.05	7.4629	4.10	13.8262
2.05	3.3427	3.10	7.7378	4.15	14.1749
2.10	3.5029	3.15	8.0001	4.20	14.5236
2.15	3.6757	3.20	8.2624	4.25	14.8943
2.20	3.8485	3.25	8.5310	4.30	15.2650
2.25	4.0275	3.30	8.7996	4.35	15.6451
2.30	4.2097	3.35	9.0792	4.40	16.0253
2.35	4.3982	3.40	9.3588	4.45	16.4148
2.40	4.5930	3.45	9.6478	4.50	16.8044
2.45	4.7885	3.50	9.9369	4.55	17.2065
2.50	4.9889	3.55	10.2353	4.60	17.6087

D	A	D	A
4.65	18.0186	6.00	31.4160
4.70	18.4286	6.05	32.0066
4.75	18.8527	6.10	32.6098
4.80	19.2768	6.15	33.2130
4.85	19.7135	6.20	33.8350
4.90	20.1502	6.25	34.4602
4.95	20.5978	6.30	35.0634
5.00	21.0455	6.35	35.7325
5.05	21.5042	6.40	36.3828
5.10	21.9629	6.45	37.0426
5.15	22.4357	6.50	37.7086
5.20	22.9085	6.55	38.3872
5.25	23.3939	6.60	39.0720
5.30	23.8793	6.65	39.7632
5.35	24.3694	6.70	40.4700
5.40	24.8720	6.75	41.1832
5.45	25.3778	6.80	41.9058
5.50	25.8951	6.85	42.6409
5.55	26.4114	6.90	43.3855
5.60	26.9392	6.95	44.1394
5.65	27.4733	7.00	44.9028
5.70	28.0168		
5.75	28.5634		
5.80	29.1163		
5.85	29.6818		
5.90	30.2536		
5.95	30.8316		

Data for Physical Hardness Tests.

Sp.	Dia.	Dia.	Dia.	Area of	Hardness
	I	II	Av.	Imp.	Number.
A1	5.158		5.16	22.5302	121
A2	4.201	4.314	4.26	14.9684	182
A3	3.780	3.675	3.73	11.3295	240
A4	3.722	3.669	3.70	11.1495	244
A5	3.505	3.514	3.51	9.9968	272
A6	3.460	3.528	3.49	9.8790	276
B1	5.278	4.970	5.12	22.2525	122
B2	4.360	4.330	4.34	15.5690	175
B3	3.780	3.741	3.76	11.5095	237
B4	3.706	3.685	3.70	11.1495	244
B5	3.758	3.675	3.71	11.2095	243
B6	3.852	3.660	3.76	11.5095	237
C1	5.500	5.432	5.47	25.5847	106
C2	4.686	4.817	4.75	18.8527	144
C3	4.134	3.989	4.06	13.5422	201
C4	4.091	4.114	4.10	13.8262	197
C5	4.291	4.210	4.50	16.8044	162
C6	4.319	4.350	4.33	15.4930	176
D1	5.436	5.401	5.42	25.0744	109
D2	4.586	4.622	4.60	17.6087	155
D3	4.063	4.099	4.08	13.6842	199
D4	4.050	4.071	4.06	13.5422	201
D5	3.830	3.790	3.81	11.7987	231

Sp.	-	Dia.	-	Dia.	-	Dia.	-	Area of	-	Hardness
		1		2		Av.		Imp.		Number.
1		5.25		5.32		5.28		23.6792		120
2		4.67		4.53		4.60		17.6087		155
3		3.855		3.94		3.90		12.4407		219
4		4.05		4.065		4.06		13.5422		201
5		3.97		4.05		4.01		13.1870		206
6		4.165		4.195		4.18		14.3820		189
E1		4.10		4.00		4.05		13.4712		202

6,000# - 2722 kilograms.

Hardness number - ratio of force, in kilograms, to area of
Impression in square millimeters.

indicated by means of a calibrated tuning fork made to vibrate by a current from a storage cell. In the armature circuit of the motor were placed a couple of rheostats which were adjusted so that the speed was near the desired value. The final adjustment was made by pressing with the finger on the plate which is over the end of the armature of the permeameter. The current was supplied from a storage battery and in the first part of the test was adjusted to ten amperes and the full number of magnetizing turns thrown in, while in the second part the current and turns were adjusted so as to give a reading on the millivoltmeter of 60000 lines per square inch.

The permeameter was operated in the following way.

Connect the positive terminal of a battery to the positive "battery" post of the instrument and the negative terminal of the battery to the other "battery" post. Connect the positive post of the millivoltmeter which goes with the instrument, to the positive "millivoltmeter" post of the permeameter.

When switch "C" is thrown to the left, (direction being measured by facing commutator end of the armature of the instrument) the millivoltmeter reads the magnetizing current, when this switch is thrown to the right the millivoltmeter reads the density in kilolines per square inch.

The switch A reverses the direction of the magnetizing current through the coils.

Switch "B" is to cause the millivoltmeter to always read in the same direction.

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The left hand dial cuts in the magnetizing turns, the number of active turns being indicated by numbers on a ring outside of the dial. The right hand dial cuts in turns which compensate for the reluctance of the magnetic circuit outside of the test bar. This latter dial is graduated so that after cutting in the desired number of turns on the left hand dial the flux is read and then the right hand dial adjusted so that it reads the value which is nearest to the value of the flux.

The millivoltmeter is calibrated for a speed of 1750 R. P. M. but we were unable to get this speed with the frequency of our tuning-fork. The tuning-fork frequency was 99.644 single vibrations per second and with seven spots on a disc on the end of the motor shaft gave 1708 R. P. M.

In the data which follows, the average value of the maximum induction, M , the average of the residual density, R , and the magnetic hardness number, $\frac{R}{C'}$, are corrected for the error due to the low speed. The value of C in the data is given in ampere-turns, that of C' in Gilberts per square centimeter, and that of M and R in kilolines per square inch.

After inserting the test bar so that it extended through the two pole pieces it was fastened in place by means of the four bolts provided for this purpose on the lower part of the pole pieces.

In order that the exciting current might be kept constant or read without working "C" so much an ammeter was inserted in the battery circuit and read instead of the millivoltmeter.

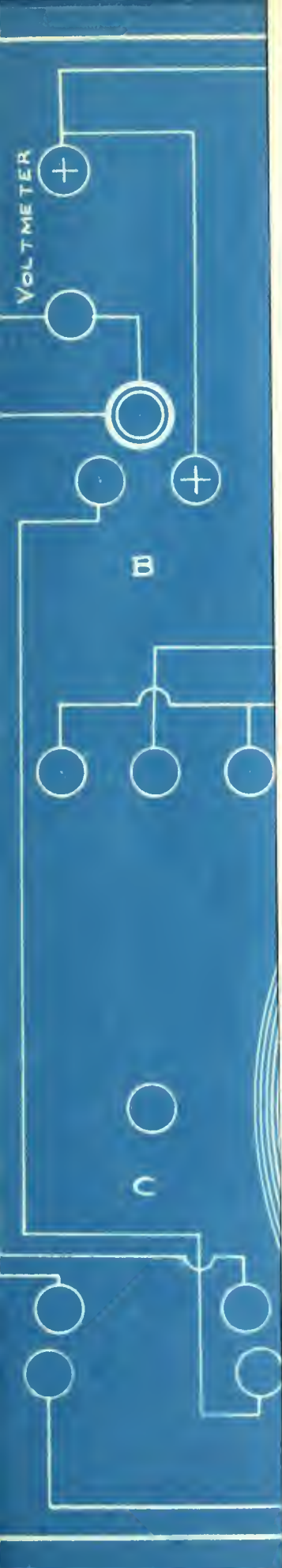
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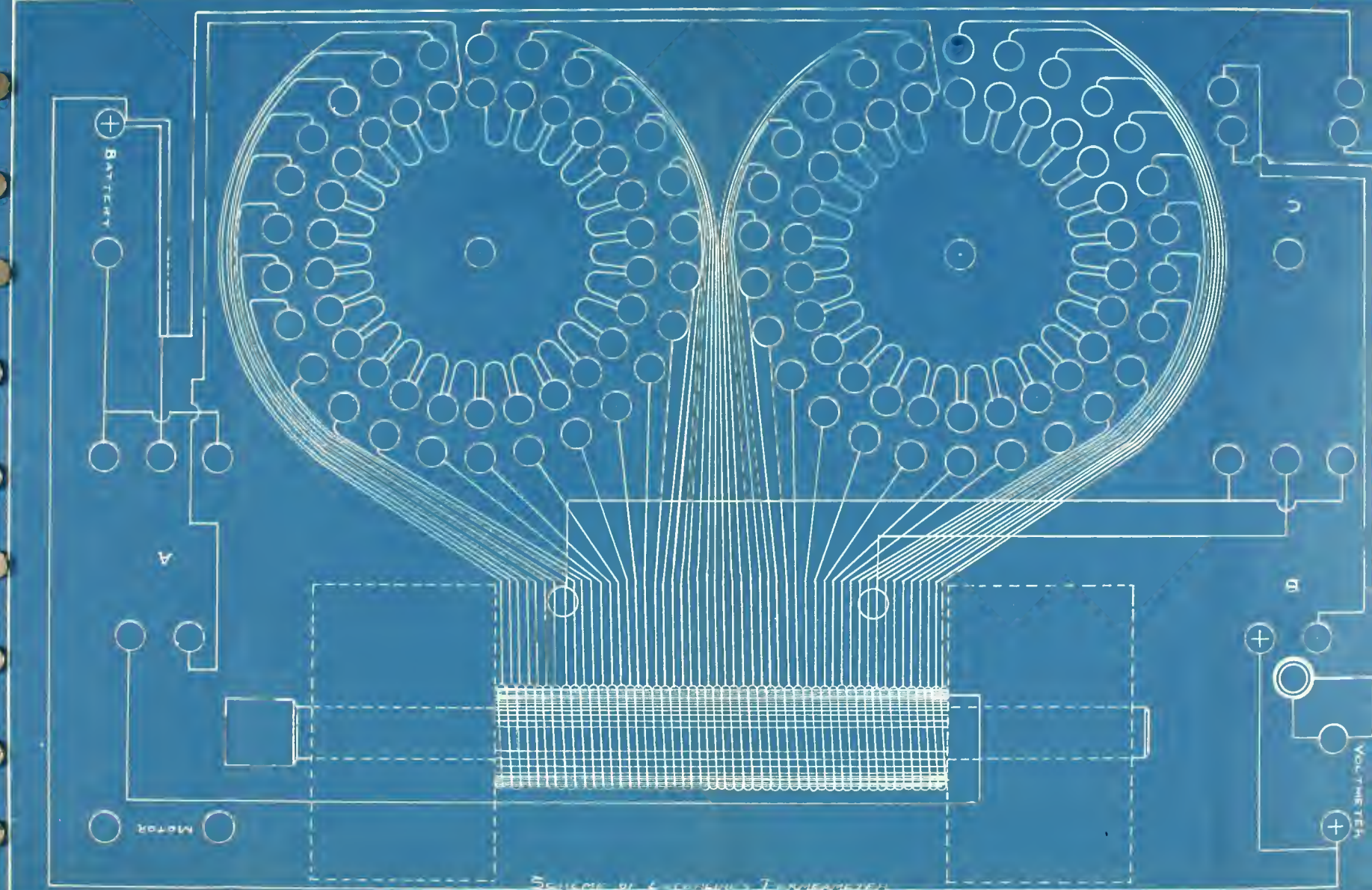
PH.D. THESIS
SUBMITTED TO THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
DEPARTMENT OF CHEMISTRY
BY
JAMES H. HARRIS

CHICAGO, ILLINOIS
1961

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1961





The assumption was made that the current readings on the millivoltmeter were accurate and so the ammeter readings were compared with these readings when switch "C" was thrown to read current.

At first an attempt was made to get a complete hysteresis loop by keeping the exciting current constant at ten amperes and varying the number of ampere-turns, reversing current and millivoltmeter switches at the proper places. However, we were unable to get any of the curves to close and practically all crossed near the end at which they should close. After spending about three days trying to remedy this difficulty it was decided to drop the idea of getting the entire hysteresis loop, which was not really needed, and proceed to obtain the Residual Density and Coercive Force. The ratio of these two quantities, Residual Density to Coercive Force, gives the magnetic hardness number, Residual Density, R , being expressed in kilolines per square inch and Coercive Force, C , in Gilberts per square inch.

To obtain these quantities, one may proceed by either of the following methods, both of which were used to see if they gave the same results.

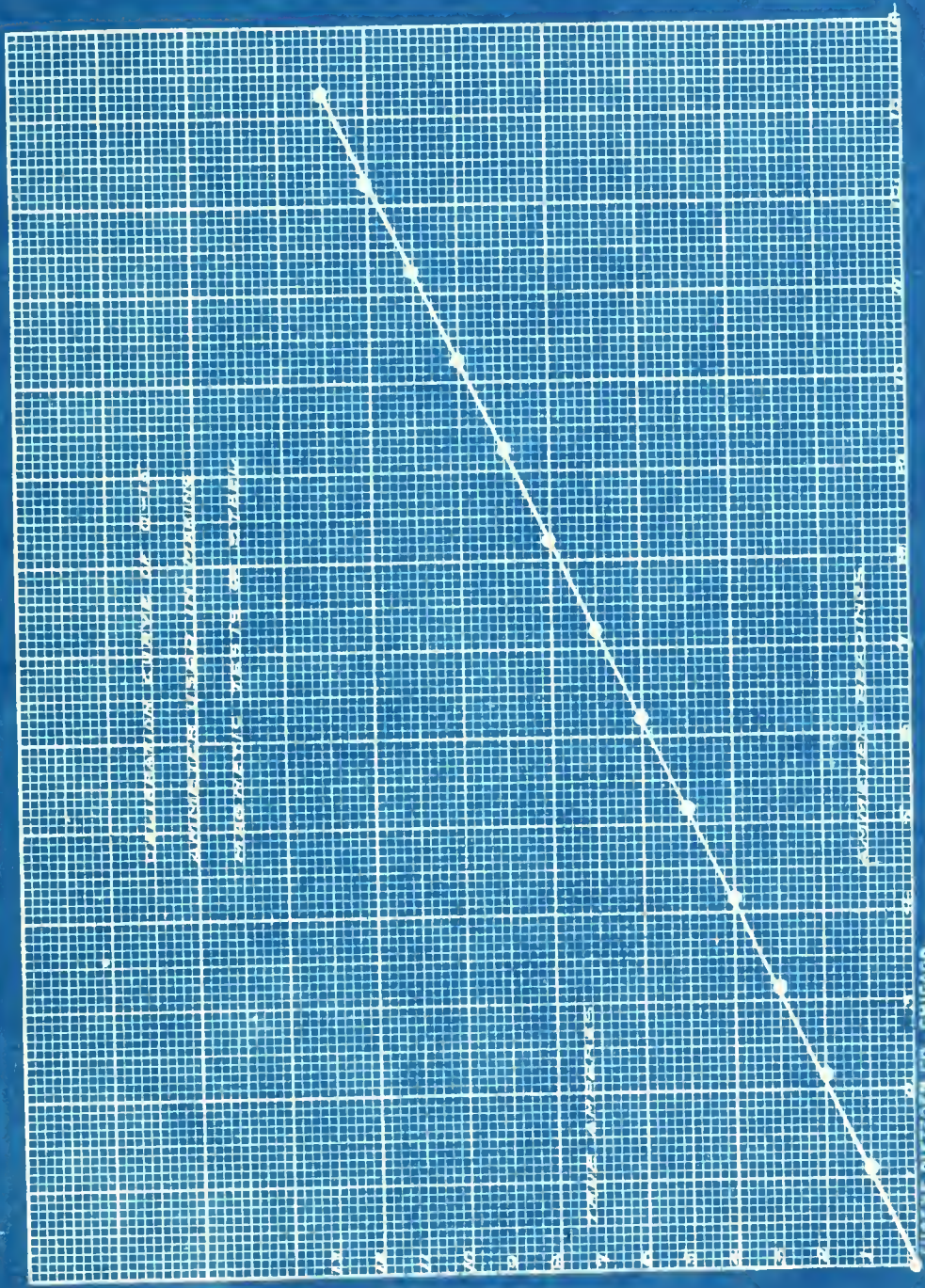
First, with a constant magnetizing current of ten amperes obtain the maximum induction, M , by cutting in turns on the left hand dial and compensating turns on the right hand dial as previously described. Now reduce the number of magnetizing turns and compensating turns to zero and read the flux as before, this gives R in kilolines per square inch. If the

Data for Calibration of Ammeter Using the Special
Millivoltmeter As a Standard.

Ammeter Readings	Millivoltmeter Readings
0	0
1.11	1
2.15	2
3.15	3
4.15	4
5.19	5
6.20	6
7.20	7
8.22	8
9.24	9
10.23	10
11.25	11
12.26	12
13.28	13

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LUDWIG DITZGEN CO., CHICAGO.

magnetizing current is now reversed by means of the switch "A" and enough ampere turns cut in to reduce the flux to zero the current and turns required to demagnetize the specimen may be read. This gives the Coercive Force, C , in ampere turns. Since the turns may be cut in only in groups of four we were not able by this method to stop the needle of the millivoltmeter at zero so the specimen would be oppositely magnetized to some extent. To overcome this difficulty we reversed our magnetizing current then reduced it to three or four amperes and cut in turns on the left hand dial until the needle was almost at zero. Now by raising the current very slowly the needle may be made to stop at zero. Again, by reading the current and turns we obtain C in ampere turns.

When switches "A" and "B" were both to the left we called the magnetization negative. Two positive and two negative readings were taken for each of the quantities magnetic induction, residual density, demagnetizing current, and turns, and the average of each of the four readings taken as the actual value of each quantity.

The second method of determining M , R , & C is similar to the method just described except that each specimen is subjected to a constant maximum induction, M , of about 60,000 lines per square inch. To obtain this we adjusted the turns (Magnetizing and Compensating) and the current so that the millivoltmeter read 60, then determined R and C as in the first method.

Our results for the magnetic hardness numbers as

determined by two methods described in the foregoing discussion show that the two methods do not give the same results. Both are shown, however,

Since the residual density and coercive force vary with the maximum induction we are inclined to think that the best comparative method would be to use a constant maximum induction.

As might be expected the heat treatment affects both the physical and magnetic hardness but not in the same ratio.

The results obtained for the physical and magnetic hardness numbers do not indicate that any definite relation exists between the two kinds of hardness.

By a comparison of the coercive force, as obtained by both methods, with the physical hardness numbers it is shown that specimens subjected to the same heat treatment indicate that there undoubtedly is a relation between these two quantities in this class of steel. The relation however is seen to be influenced by the heat treatment to which the steel was subjected.

Also, it seems that neglecting specimens A and D (the former not being heated after we received it and the latter not above the hardening heat) that there is a constant relation. It is possible that had all the specimens been kept for say five or six hours at temperatures above the hardening heat a definite relation would be found to exist between the coercive force and physical hardness number for any class of carbon steels. Specimen #1 seems to indicate that this relation differs with different classes of steels.

As a result of our tests we feel satisfied that if a relation can be found to exist between Residual Density and Coercive Force that a relation in all probability exists between the Physical and

Magnetic Hardness of this class of steels. As previously stated we find that there is in all probability a relation between Coercive Force and Physical Hardness and since the only relation not known to satisfy our investigation is that between Residual Density and Coercive Force we are led to the above conclusion concerning the relations between the Magnetic and Physical Hardness of these Carbon Steels.

Sp. Mag. M.		R.	C.	(M. Average) (M. R. C.)			C'	$\frac{R}{C}$	20.
A1	$\frac{1}{2}$	86	40.5	9.76					
"	-	89	46	11.6					
"	$\frac{1}{2}$	86	38.5	9.68					
"	-	89	45	10.8	89.7	43.5	10.46	5.174	8.42
A2	$\frac{1}{2}$	77	41	18.2					
"	-	79	43.5-19.2						
"	$\frac{1}{2}$	76	41	18.2					
"	-	76	42.25-19.4	78.9	42.9	18.75	9.276	4.52	
A3	$\frac{1}{2}$	70.5	30	22.4					
"	-	70	32	24					
"	$\frac{1}{2}$	68	29.5-22.4						
"	-	70.4	32.5-24.2	71.4	31.8	23.25	11.502	2.76	
A4	$\frac{1}{2}$	63.4	33	28					
"	-	66.8	35.7-24						
"	$\frac{1}{2}$	63.4	33	27.6					
"	-	65	36.5-23.6	66.2	35.3	25.8	12.763	2.80	
A5	$\frac{1}{2}$	64	34	27					
"	-	70	37.5-29.2						
"	$\frac{1}{2}$	64.5	34	27					
"	-	68	36.5-28.8	68.2-36.4	28		13.852	2.63	
A6	$\frac{1}{2}$	64	31.8-28.6						
"	-	66	35.8-29.2						
"	$\frac{1}{2}$	66	33.2-28.8						
"	-	70	36	28.8	68.1-35.0	28.84	14.267	2.45	

Sp.	Mag.	M.	R.	C.	(Average)			C'	21.	$\frac{R}{C'}$
					(M.	R.	C.)			
B1	$\frac{1}{2}$	77	24.3	7.84						
"	-	82.5	27.5	8.8						
"	$\frac{1}{2}$	77	23	8.8						
"	-	81.4	27	8.72	81.5	26.07	8.54	4.225	6.17	
B2	$\frac{1}{2}$	69.8	29	14						
"	-	74	31.5	14.64						
"	$\frac{1}{2}$	71	28.8	15.6						
"	-	75.5	32.5	14.84	74.4	31.20	14.77	7.307	4.30	
B3	$\frac{1}{2}$	73	27.8	18.48						
"	-	74.6	29	19.56						
"	$\frac{1}{2}$	69.8	26	18.24						
"	-	71.8	27	19.32	74.1	28.22	18.9	8.350	3.37	
B4	$\frac{1}{2}$	70	31.5	21.6						
"	-	72.4	33	21.76						
"	$\frac{1}{2}$	70	31	21.38						
"	-	72	34	22.2	72.8	33.19	21.75	10.760	3.08	
B5	$\frac{1}{2}$	68.4	32.3	20.3						
"	-	71.4	34.7	21.6						
"	$\frac{1}{2}$	68.5	31.7	20						
"	-	71	34	20.8	71.5	34.01	20.7	10.240	3.32	
B6	$\frac{1}{2}$	70	29.6	22.2						
"	-	70.4	32	20.6						
"	$\frac{1}{2}$	73	30	19.7						
"	-	73.5	30.4	20.6	73.5	30.73	20.8	10.290	2.99	

Sp.Mag.	M.	R.	C.	((M.	Average R.) C.)	C'	$\frac{R}{C}$	
C1	$\frac{1}{2}$	75.8	21	6.48					
"	-	76.5	24	6.8					
"	$\frac{1}{2}$	73.8	20.2	6.32					
"	-	79	24.3	7.36	78.2	23.0	6.74	3.334	6.91
C2	$\frac{1}{2}$	75	33	13.1					
"	-	79	36	13.76					
"	$\frac{1}{2}$	78	33	12.96					
"	-	80	36	13.6	79.9	35.3	13.36	6.609	5.35
C3	$\frac{1}{2}$	71.5	31.2	18.96					
"	-	72.5	33.2	20.4					
"	$\frac{1}{2}$	69.6	31	18.72					
"	-	71.5	34.5	20.16	73.1	33.4	19.46	9.627	3.56
C4	$\frac{1}{2}$	70	33	16.84					
"	-	73.5	36.8	18					
"	$\frac{1}{2}$	70.8	32.3	16.85					
"	-	73	36.5	17.76	73.6	35.5	17.36	8.588	4.13
C5	$\frac{1}{2}$	66.5	40	19.68					
"	-	70	44	20.16					
"	$\frac{1}{2}$	68	41	19.6					
"	-	71.8	44.5	20.5	70.8	43.4	20	9.894	4.39
C6	$\frac{1}{2}$	64	38.5	20.1					
"	-	68	39	21.6					
"	$\frac{1}{2}$	63.5	38	20.1					
"	-	67.5	39	20.5	67.6	39.6	20.57	10.176	3.89

Sp.	Mag.	M.	R.	C.	((M.	Average R.) C.)	C'	$\frac{R}{C'}$
D1	$\frac{1}{2}$	81	32	8.77					
"	-	85	36.5	9.6					
"	$\frac{1}{2}$	81	32	9.05					
"	-	84	37	10.4	90.2	35.2	9.45	4.675	7.54
D2	$\frac{1}{2}$	74	46.4	18.4					
"	-	78.5	48	17.92					
"	$\frac{1}{2}$	73	44	17.76					
"	-	79	47.5	17.02	78	47.6	17.72	8.766	5.43
D3	$\frac{1}{2}$	71.5	39.8	22.8					
"	-	75.5	42.6	24					
"	$\frac{1}{2}$	71	39.5	22.2					
"	-	76	42.5	23.2	75.2	42.1	23.05	11.403	3.69
D4	$\frac{1}{2}$	68	44	20.64					
"	-	70.3	47	21.72					
"	$\frac{1}{2}$	67	43.8	21.02					
"	-	71	48	20.8	70.8	46.8	21.05	10.413	4.50
D5	$\frac{1}{2}$	68.6	38	26					
"	-	70.8	42	26.8					
"	$\frac{1}{2}$	68	38	25					
"	-	70.8	40	26.8	71.3	40.5	26.3	13.011	3.11
D6	$\frac{1}{2}$	67	38.5	26.8					
"	-	71	42	26.8					
"	$\frac{1}{2}$	67.5	39.5	26					
"	-	71	42.5	26.8	70.8	41.6	26.6	13.159	3.17

Sp.	Mag.	M.	R.	C.	(Average)			24.	$\frac{R}{C'}$
					(M.	R.	C.)	C'	
1	$\frac{1}{2}$	71	17	5.4					
"	-	79	22	6.96					
"	$\frac{1}{2}$	71	17	5.44					
"	-	78	21.8	6.96	76.6	19.93	6.21	3.072	6.491
2	$\frac{1}{2}$	82	32	12.88					
"	-	82.5	30	12.72					
"	$\frac{1}{2}$	81.5	30	12.64					
"	-	81.5	30	12.80	83.8	31.25	12.51	6.189	5.05
3	$\frac{1}{2}$	70.5	25	18					
"	-	73.5	27.8	19.44					
"	$\frac{1}{2}$	72	26.3	18.24					
"	-	74.5	28	19.36	74.4	27.46	18.76	9.281	2.96
4	$\frac{1}{2}$	70.	32	17.54					
"	-	72.8	36	18.4					
"	$\frac{1}{2}$	70	32.5	17.04					
"	-	71.8	35.8	18.36	72.8	34.94	17.83	8.821	3.97
5	$\frac{1}{2}$	67.8	28.5	16.4					
"	-	70.5	32	18.24					
"	$\frac{1}{2}$	66.5	29	16					
"	-	70.5	32	18	70.5	31.14	17.16	8.489	3.68
6	$\frac{1}{2}$	70	27.4	15.6					
"	-	73	30.5	17.4					
"	$\frac{1}{2}$	67.5	27	15.36					
"	-	71.2	30	17.16	72.1	29.3	16.38	8.103	3.63
E1	+	75.8	32	18.84					
"	-	78.7	35.3	20.16					
"	+	76.5	32.2	18.72					
"	-	76.8	35.3	20.16	78.8	34.5	19.47	3.63	3.59

Constant Maximum Induction, M, of 61746.

Average.

Average.							
Sp.	Mag.	R	C	(R	C)	C'	$\frac{R}{C'}$
A1	$\frac{1}{2}$	29	8.88				
"	-	29	9.00				
"	$\frac{1}{2}$	29	8.88				
"	-	29	8.76	29.	8.88	4.393	6.60
A2	$\frac{1}{2}$	35.5	16.96				
"	-	36	17.40				
"	$\frac{1}{2}$	35	16.56				
"	-	37	17.28	36.75	17.05	8.435	4.36
A3	$\frac{1}{2}$	29	21.12				
"	-	30	22.56				
"	$\frac{1}{2}$	28.8	22.32				
"	-	30	22.80	29.45	22.20	10.982	2.68
A4	$\frac{1}{2}$	33.5	26.56				
"	-	36	27.84				
"	$\frac{1}{2}$	34	26.56				
"	-	35	27.20	35.45	27.04	13.377	2.65
A5	$\frac{1}{2}$	29	27.2				
"	-	32	27.2				
"	$\frac{1}{2}$	29.5	27.2				
"	-	32	27.2	31.35	27.2	13.456	2.33
A6	$\frac{1}{2}$	30	27.84				
"	-	32.2	28.56				

Sp. Mag.		R.	C.	(Average) (R. C.)		C'	$\frac{R}{C}$	26.
A6	$\frac{1}{2}$	30.8	27.88					
"	-	32	28.80	32.02	28.27	13.985	2.39	
B1	$\frac{1}{2}$	20	7.2					
"	-	24.8	8.24					
"	$\frac{1}{2}$	20	7.36					
"	-	25	8.24	22.90	7.76	3.839	5.99	
B2	$\frac{1}{2}$	26.5	12.96					
"	-	28	13.68					
"	$\frac{1}{2}$	26	12.96					
"	-	27.5	13.68	27.66	13.32	6.589	4.20	
B3	$\frac{1}{2}$	26.6	18.24					
"	-	28	18.24					
"	$\frac{1}{2}$	24.7	18.00					
"	-	27.8	18.36	27.46	18.21	9.008	3.05	
B4	$\frac{1}{2}$	26	20.04					
"	-	28.5	21.84					
"	$\frac{1}{2}$	26.5	20.04					
"	-	29.3	21.84	27.36	20.94	10.359	2.73	
B5	$\frac{1}{2}$	30	19.92					
"	-	30	20.88					
"	$\frac{1}{2}$	28	20.16					
"	-	31	20.88	30.48	20.46	10.122	3.01	
B6	$\frac{1}{2}$	26	18.88					
"	-	27.2	20.00					
"	$\frac{1}{2}$	25.2	18.88					
"	-	27	20.00	27.00	19.44	9.617	2.81	

								27.
Sp. Mag.		R.	C.	(Average (R. C)		C'	$\frac{R}{C'}$	
C1	$\frac{1}{2}$	20.5	6.48					
"	-	22.5	6.72					
"	$\frac{1}{2}$	21	6.00					
"	$\frac{1}{2}$	24.5	6.96	22.66	6.54	3.235	7.01	
C2	$\frac{1}{2}$	25	12.8					
"	-	30	12.8					
"	$\frac{1}{2}$	25	12.6					
"	-	28.5	13.12	27.79	12.83	6.347	4.38	
C3	$\frac{1}{2}$	29.5	19.00					
"	-	30	18.80					
"	$\frac{1}{2}$	28.5	18.80					
"	-	29.5	19.00	30.12	18.90	9.350	3.22	
C4	$\frac{1}{2}$	28.5	16.10					
"	-	31	16.10					
"	$\frac{1}{2}$	29	16.56					
"	-	31	16.08	30.63	16.21	8.019	3.82	
C5	$\frac{1}{2}$	37	19.80					
"	-	38.5	19.20					
"	$\frac{1}{2}$	36.5	19.00					
"	-	36.5	19.60	38.03	19.40	9.597	3.86	
C6	$\frac{1}{2}$	36	20.60					
"	-	36.5	19.00					
"	$\frac{1}{2}$	35	19.80					
"	-	36.5	19.80	36.88	19.80,	9.795	3.77	

Sp. Mag.	R.	C.	(Average)		C'	$\frac{R}{C'}$	23.
			(R.	C.)			
D1	$\frac{1}{2}$	25.6	8.24				
"	-	25.5	8.24				
"	$\frac{1}{2}$	25.3	7.84				
"	-	24.5	7.84	25.84	8.04	3.977	6.49
D2	$-\frac{1}{2}$	39	14.72				
"	-	40.5	15.84				
"	$\frac{1}{2}$	39	14.72				
"	-	38	14.40	40.10	14.92	7.381	5.43
D3	$\frac{1}{2}$	36.1	20.40				
"	-	38.7	21.84				
"	$\frac{1}{2}$	35	20.16				
"	-	37	21.00	37.6	20.86	10.319	3.64
D4	$\frac{1}{2}$	39.4	20.64				
"	-	40.5	21.72				
"	$\frac{1}{2}$	38.3	21.12				
"	-	39.3	20.80	40.37	21.07	10.423	3.87
D5	$\frac{1}{2}$	36.8	26.06				
"	-	36	24.80				
"	$\frac{1}{2}$	35	24.80				
"	-	36	24.96	36.83	25.15	12.442	2.95
D6	$\frac{1}{2}$	36	24.80				
"	-	36.5	25.92				
"	$\frac{1}{2}$	35	24.56				
"	-	38	25.60	36.78	25.22	12.476	2.94

Sp. Mag.	R.	C.	Average		C'	$\frac{R}{C}$	29.
			(R.	C.)			
1	$\frac{1}{5}$	18.5	5.36				
"	-	18	5.72				
"	$\frac{1}{5}$	17	5.80				
"	-	18.5	6.00	18.24	5.97	3.953	4.67
2	$\frac{1}{5}$	22.5	10.72				
"	-	25.5	11.76				
"	$\frac{1}{5}$	23	11.04				
"	-	25	12.36	24.59	11.47	7.684	3.20
3	$\frac{1}{5}$	22.3	16.96				
"	-	23.5	18.88				
"	$\frac{1}{5}$	21.3	16.96				
"	-	23.2	18.72	23.15	17.88	8.845	2.68
4	$\frac{1}{5}$	30	16.80				
"	-	32	17.00				
"	$\frac{1}{5}$	30.2	16.00				
"	-	33	17.30	32.07	16.77	8.296	3.86
5	$\frac{1}{5}$	25.3	7.84				
"	-	28	8.88				
"	$\frac{1}{5}$	25.8	7.84				
"	-	27.5	8.56	27.31	8.28	4.096	6.67
6	$\frac{1}{5}$	24	7.76				
"	-	26	8.02				
"	$\frac{1}{5}$	24	7.68				
"	-	27	8.28	25.87	7.94	3.928	6.59
El	$\frac{1}{5}$	33	16.90				
"	-	30.5	15.20				
"	$\frac{1}{5}$	34	17.12				
"	-	34	15.88	33.71	16.27	8.049	4.19

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Sp.	(1) $\frac{R}{C'}$	(11) $\frac{R}{C'}$	Physical Hardness No.	(1) $\frac{C'}{P. H. No.}$	(11) $\frac{C'}{P. H. No.}$
A1	8.42	6.76	121	.0427	.0765
A2	4.52	4.36	182	.0509	.0463
A3	2.76	2.75	240	.0479	.0457
A4	2.80	2.65	244	.0523	.0548
A5	2.63	2.33	272	.0509	.0414
A6	2.45	2.39	276	.0517	.0506
B1	6.17	5.99	122	.0346	.0314
B2	6.30	4.20	175	.0417	.0376
B3	3.37	3.05	237	.0352	.0380
B4	3.08	2.73	244	.0441	.0424
B5	3.32	3.01	243	.0421	.0416
B6	2.99	2.81	237	.0434	.0406
C1	6.91	7.01	106	.0314	.0305
C2	5.35	4.38	144	.0459	.0440
C3	3.56	3.22	201	.0479	.0465
C4	4.13	3.82	197	.0436	.0407
C5	4.39	3.86	162	.0610	.0592
C6	3.89	3.77	176	.0578	.0556
D1	7.54	6.49	109	.0429	.0365
D2	5.43	5.43	155	.0565	.0476
D3	3.69	3.64	109	.0573	.0518
D4	4.50	3.87	201	.0518	.0518
D5	3.11	2.97	231	.0563	.0538
D6	3.17	2.94	230	.0572	.0542

Sp.	(I) $\frac{R}{C'}$	(II) $\frac{R}{C'}$	Hard. No.	(I) $\frac{C'}{H. No.}$	(II) $\frac{C'}{H. No.}$
1	6.49	4.67	120	.0256	.0329
2	5.05	3.20	155	.0399	.0495
3	2.96	2.68	219	.0424	.0404
4	3.97	3.86	201	.0438	.0412
5	3.68	6.67	206	.0412	.0198
6	3.3	6.69	189	.0428	.0207
E1	3.59	4.19	202	.0476	.0398



